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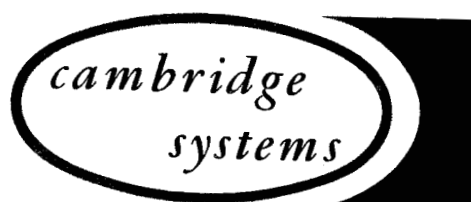
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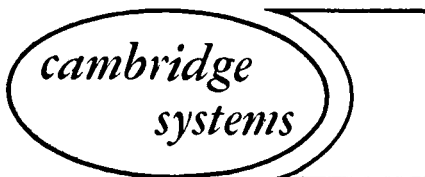
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DESIGN and TESTING
of an
AEROSPACE DEW POINT HYGROMETER

FINAL REPORT

NASA Contract No. NAS 9-2917
2 November 1964

Prepared For ►
NASA Manned Spacecraft Center
Crew Systems Division

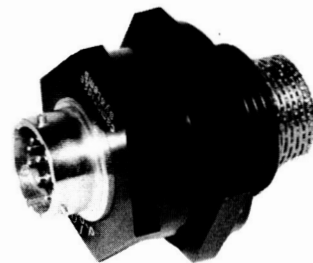


50 HUNT STREET • NEWTON, MASSACHUSETTS • 617 969-7680

AEROSPACE
HYGROMETER SYSTEM



CONTROL UNIT 137-C2



SENSOR 137-S3-P



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ABSTRACT

27375

This document describes the design and testing of an Aerospace Dew Point Hygrometer System, developed for use in spaceflight instrumentation systems. The hygrometer described is of the thermoelectrically cooled and optically detected dew condensing type. The hygrometer system consists of a miniature dew point sensing assembly, and a separate control amplifier, power supply, and signal conditioning package. The components are designed to meet rigorous space flight qualifications. Tests conducted to demonstrate that the hygrometer system meets such qualifications are described.



NOTICE

The availability of circuit diagrams and constructional details for the instrument(s) described in this document does not imply that the instrument(s) are not covered by U. S. and Foreign patents.

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SECTION 1

BACKGROUND

In previous space flights, no information was obtained regarding atmospheric relative humidity or dew point temperature. This information is desirable as an aid in evaluating the performance of water removal systems and in maintaining the most desirable space craft environment in terms of both pilot comfort and equipment protection. The results of high humidity and moisture condensation have been demonstrated in previous flights by corrosion and equipment failures. A system for measuring dew point temperature is then beneficial in preventing recurrences of a problem which becomes even more acute with the increasing length of manned missions. The basic objective of the program described in this report was the design and testing of a suitable dew point hygrometer for such application.

Section 1.1 Historical Information

Dew point hygrometry is an old and well-established art. The availability of thermoelectric cooling devices in the late 1950's made possible a revolution in this class of instrument, since such devices permitted the normally cumbersome mechanical refrigeration systems required in such an instrument to be replaced with simple, solid state, heat pumps. Recognizing the advantages of a fully automatic, thermoelectrically cooled dew point hygrometer, development of instruments of this type commenced in 1959. Some of the first fully operational instruments were developed and delivered under Air Force Contract No. AF19(604)-8812. Subsequent effort, directed toward further miniaturization and operational testing of dew point hygrometry systems, was carried out under Air Force Contract No. AF19(628)-410, and under U.S. Army Electronic Command's Contract No. DA-36-039-AMC-03763(E). The development of the Aerospace Dew Point Hygrometer System described in this report is therefore the culmination of information from these previous contracts, and represents a significant advance in hygrometry and spacecraft instrumentation.

SECTION 2

PROGRAM OBJECTIVE

The basic objective of this program was the design, fabrication, and testing of an accurate and reliable instrument for measuring dew point temperatures in life supporting atmospheres, as encountered in space craft systems. The intended application for the resulting instrument is for environmental testing of manned spacecraft and eventual addition to the spacecraft instrumentation system.

As a goal, the following target specifications for the instrument were established:

2.1 General Description

The required system would consist of a small sensor, suitable for providing an automatic, continuous measurement of the dew point temperature, containing the necessary assemblies for sampling and detecting the dew point temperature. The sensing element should be of such a design that it could be inserted through a boss in an environmental control system duct, with a minimum of pressure drop across the inserted sensor. A separate system component, containing the power supply, amplifier, and signal conditioning circuitry for the sensor would be required. The signal conditioning package could then be located some distance from the sensor. All portions of the instrument would have to operate in a 100% oxygen atmosphere. Also, the system design should lend itself to the rigors of space flight with a minimum of modifications.

2.2 Target Performance Specifications

2.2.1 Range

The instrument should be capable of measuring dew points between 0°F and $+150^{\circ}\text{F}$, with ambient temperatures within the range of $+40^{\circ}\text{F}$ to $+150^{\circ}\text{F}$. The dew point depression capability for the sensor should be sufficient to permit measurement of atmospheric conditions between 10% and 100% RH.

2.2.2 Response

The time for the system to achieve a 63% response to a 20°F step change in dew point should be in the order of five seconds or less.

2.2.3 Accuracy

The instrument should be capable of measuring dew point to an accuracy of $\pm 1^\circ\text{F}$, which corresponds to $\pm 0.67\%$ of span covered.

2.2.4 Output

The output of the system should be a 0-5 volt dc low impedance, linear, temperature signal.

2.2.5 Power Requirement

The system should not require more than 5 watts of operating power, and a lower power requirement would be desirable.

2.2.6 Weight

The total system weight should not exceed 1.5 pounds.

The design effort required under this contract was expended with the foregoing target specifications in mind.

SECTION 3

DESCRIPTION OF SYSTEM

Due to the large amount of work which had been carried out under earlier programs (see Section 1), it was logical that the design be based on previous work. The Dew Point Sensor, for example, had been prototyped under previous contract DA-036-039-AMC-03763(E). Much of the design effort expended on the sensor was in the direction of ruggedization and mounting modifications.

3.1 Principle of Operation

The functional block diagram for the Miniature Dew Point Hygrometer is shown in Dwg. SK 139-032 in the rear of this report. The sensing mirror surface, shown on the left-hand portion of the block diagram, is thermally bonded to, but electrically insulated from, a small thermoelectric cooling module. The module, when excited with direct current of proper polarity, causes heat to be pumped from the mirror and thus lowers the temperature of the mirror surface. As the mirror temperature reaches the dew point, the process of condensate formation on the mirror surface commences. The presence of the condensate on the mirror surface causes the visible light reflection characteristic of the mirror to change. The mirror surface is illuminated by an incandescant source in such a fashion that the change in reflectivity can be detected by the DIRECT photoresistor in the optical-electronic sensing bridge. The detector output is in the form of an electrical signal which, after differentiation, serves as the input to the operational amplifier shown in the diagram. The signal from the operational amplifier controls the output amplifier, which, in turn, controls the direct current supplied to the thermoelectric cooling module in direct proportion to the input signal. Using this proportional direct current to excite the cooler in a negative sense, i. e., causing the mirror to become cooler when a decrease in condensate occurs, the system will stabilize on, and control about, a particular dew layer thickness. A measurement of the mirror temperature under stabilized conditions is taken to be a measurement of the dew point. The mirror temperature is sensed by a platinum resistance thermometer.

3.2 Circuit Description

The electrical aspects of the hygrometer detector and control circuits are shown in Dwg. SK139-032. The circuit is designed to operate as follows:

The formation of condensate on the mirror surface causes a reduction in the amount of light received at the photoresistor labeled DIRECT, and a consequent change in the device resistance. This photoresistor and a second photoresistor, labeled BIAS, used for temperature compensation, comprise the optical portion of the bridge circuit. Resistors R101 and R103 and potentiometer R102, labeled BALANCE, complete the conventional bridge. The bridge output signal is taken from the wiper of the Balance Control and from the common point of the photoresistors. The signal from the common point on the photoresistors is differentiated before being added into the inverting input of the operational amplifier. Stable operation is insured by use of over 60 db of negative feedback. The output of the operational amplifier is then fed to Q101, which serves as a driver stage for the output current transistor Q102. An unbalance condition in the photoresistor bridge causes Q102 to become more conductive and permits current to flow through the thermoelectric cooler TE-101, causing its surface to become cool. When the surface has cooled to the dew point, condensate forms on the mirror surface and tends to force the photoresistor bridge towards the balance point, reducing the amount of cooling proportionately until an equilibrium situation is established, whereby a film of condensate is maintained on the mirror surface. The BALANCE control also serves to introduce the offset voltage in the reference input necessary in any operational amplifier.

Stability of the bridge balance point is insured through the use of a mechanical light adjustment located in the path between the light source and the BIAS photoresistor, shown in Fig. 1. This adjustment is made during manufacture to provide equal light intensity on both the BIAS and the DIRECT photoresistors. This provision minimizes the difference in the temperature coefficients to the photoresistors and therefore minimizes variation in bridge output due to varying temperature conditions. It is not necessary to reposition this adjustment unless a photoresistor or the light bulb is replaced.

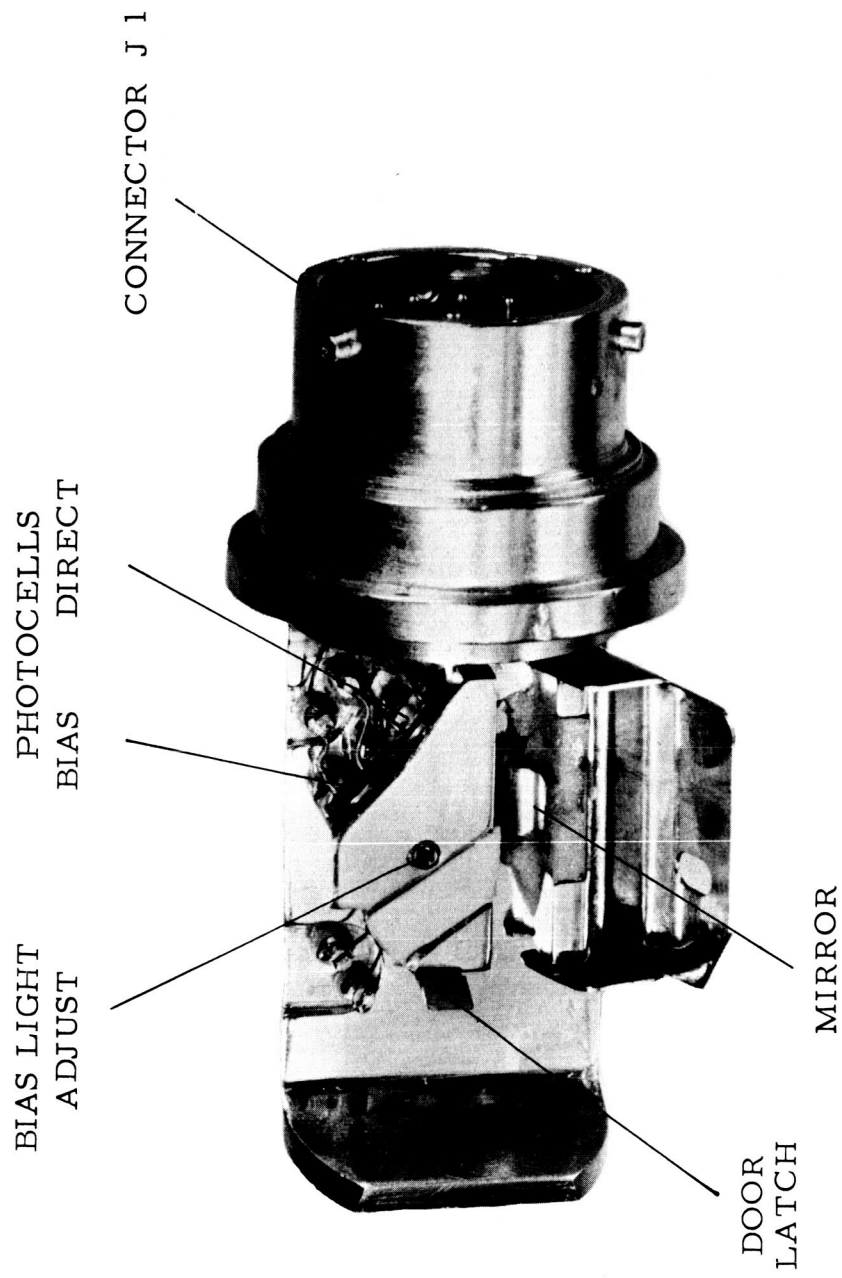


FIG. 1
SENSOR CONNECTOR ASS'Y

The BALANCE Control, R102, adjusts the bridge balance point but more particularly, provides an adjustment on the thickness of condensate on the mirror surface. It is through the proper adjustment of this control and the consequent adjustment of dew layer thickness during checkout of the hygrometer that long-term field operation of the unit is obtained even in the presence of mirror contaminants. The BALANCE control also serves to introduce the offset voltage in the reference input necessary in any operational amplifier.

The Readout Circuitry, Dwg. SK-139-005, operates independently of the Control Circuitry. Referring to the schematic, the platinum resistance thermometer, RT201, embedded in the mirrored surface, is utilized in a conventional three-wire bridge arrangement to obtain a voltage corresponding to the dew point temperature. The bridge output is fed into an operational amplifier, A201. The output of the amplifier is the output of the complete dew point temperature system.

There are two adjustments associated with the Readout Circuitry, the ZERO and SPAN controls. The ZERO control is adjusted to balance the bridge for a resistance representative of 0°F , and also to compensate for any small offset voltage in the amplifier. The SPAN control adjusts the gain of the amplifier so that when the bridge is unbalanced representative of $+150^{\circ}\text{F}$, the output of the amplifier is correct. Stability is insured by the use of negative feedback and temperature compensated components.

The primary power for the AEROSPACE HYGROMETER SYSTEM is $28 \pm 4\text{VDC}$. This power is fed into a transistorized inverter operating at about 3 KC. The inverter supplies power for a positive 15 volt supply, a negative 15 volt supply, and a 0.5 volt, 2 ampere, supply to operate the thermoelectric cooler. The two 15 volt supplies are used to power the operational amplifiers and the optical and temperature measuring bridges. These supplies are highly regulated and temperature compensated. The low voltage supply is not regulated as this consumes unnecessary power. All rectifiers in the power supplies are conservatively rated germanium devices to reduce forward voltage drops.

3.3 Calibration

Calibration of the AEROSPACE HYGROMETER SYSTEM is accomplished by calibration of the Readout Circuitry by conventional resistance

substitution techniques. The Control Circuitry, when properly aligned, automatically controls on the correct dew point, since this is a primary measuring scheme.

SECTION 4

TEST RESULTS

In order to determine that the system as designed met the target specification, the system was subjected to a variety of test situations. The results of these tests are as follows.

4.1 Range

The dew point temperature range is determined primarily by the depression characteristics of the thermoelectric cooler at that temperature. Theoretically, the depression capabilities increase approximately $1/3^{\circ}\text{F}$ per $^{\circ}\text{F}$. However, in actual practice, heat loading from the air, thermometer leads, and insulation reduce this figure to approximately $1/10^{\circ}\text{F}$ per $^{\circ}\text{F}$. The measured depression at $+40^{\circ}\text{F}$ is, conservatively, 50°F ; at $+75^{\circ}\text{F}$ the depression is over 60°F ; and at $+150^{\circ}\text{F}$, the depression is 70°F indicating that the instrument exceeds the depression specification by over 10°F for most of the temperature range.

4.2 Response

The response of the system is directly proportional to the cooling capabilities or depression of the system, and also directly proportional to the aspiration rate through the sensor; that is, the aspiration rate and depression are inversely related. Under conditions of maximum aspiration, the time for a 63% response to an approximate 20°F step change in dew point was measured about 3 seconds. Faster response is achieved by reducing the aspiration rate, with some sacrifice in sampling speed. A check on the actual step change in dew point is difficult, since the equipment that is being checked represents the state of the art in terms of response.

4.3 Accuracy

The accuracy of the AEROSPACE HYGROMETER SYSTEM as checked against a Cambridge Systems, Inc., Model 108, Thermoelectric Dew Point Hygrometer, is better than $\pm 1^{\circ}\text{F}$, over the entire range.

4.4 Linearity

In the worst case the deviation from linearity is less than 2°F , over the range of 0°F to 150°F . The curve is due to the Callendar-Van Dusen characteristics of the platinum sensor, and also to the loading on the temperature measuring bridge.

4.5 Stability

The measured temperature drift of the instrument is approximately $150 \text{ uv}/^{\circ}\text{F}$; or $.0003\%/^{\circ}\text{F}$. The long term drift is about $\pm 10 \text{ mv}$, or about $\pm 0.2\%$ of span.

4.6 Power Requirements

The power required by the instrument while operating at typical depression, that is, for dew points about 30°F below ambient, is approximately 100 ma at 28 VCD , or 2.8 watts . For variations in supply voltage the input current changes proportionately. Maximum power is required by the system when the cooler is operating at full capability; such as when the instrument is initially turned on or when there is a step drop in dew point. Under these conditions the power requirement is approximately 160 ma at 28 VDC , or 4.5 watts .

SECTION 5

RECOMMENDATIONS FOR IMPROVEMENT

5.1 Accessibility

Accessibility in the sensor Model 137-S3-P is quite satisfactory. However, in case of component failure in the Control Unit it would be desirable to have improved accessibility for replacement. This may be accomplished by modification of the printed circuit board mounts to permit the boards to pivot up and expose the circuit side.

5.2 Component Failure

The only components that failed during the entire period of testing were the inverter transistors on the power supply circuitry. This was traced to transients that, under certain conditions, could exceed the ratings on the transistors. Protective diodes have been added, and no component failures have subsequently occurred.

The single component with limited life is the light bulb. This device has a rated life of 1,000 hours. Numerous precautions, such as reduced operating voltage, preselection, pre-aging and shock isolation, are taken to insure greatly extended life. From a maintenance standpoint, it may appear desirable to have a clip-in bulb. However, in actual practice the present arrangement (bulb soldered in) may prove superior, as no contacts are depended upon for connections. There is the possibility that a second lamp, operated in parallel with the first, could be incorporated to improve reliability.

5.3 Construction

General fabrication techniques used in the system appear satisfactory. Areas where improvement is possible are the following:

- a) Printed circuit board mountings, for reasons specified in Section 5.1 of this report.
- b) Cord wood stacking in the regulator circuitry in the power supply. This should be ruggedized and assembled with more concern for appearance.

- c) Inverter transformer should be encapsulated.
- d) The printed circuit protective compound used was too thick.
- e) The printed circuit boards may be modified to improve wiring and accessibility. Components in the inverter circuitry should be rearranged to accommodate the two zener diodes, added in Section 5.2, above.
- f) In the sensor, methods of construction appear very satisfactory with possible over-design on strength and rigidity. The sensor can be streamlined carefully to reduce weight and not seriously impair the present rugged construction.

5.4 Pressure Drop, Mounting Arrangements, Response and Depression

The original specification on the maximum pressure drop of the system was one inch of water or less. Calculations with the original duct size and coefficients of the gas involved gave a pressure drop of considerably less than one inch of water across the sensor. The pressure drop across the sensor determines the aspiration rate through the sensor, with its corresponding effects on depression and response. The range of flow rates through the duct may typically vary by a factor of ten before resulting in significant effects on response and depression. If the flow rate through the duct is insufficient, the aspiration path through the sensor itself can be easily enlarged, minimizing the problem of clogging.

5.5 Radio Frequency Interference

An inverter circuit is utilized in the system to convert the primary 28 VDC power into useful voltages to operate the various circuitry. An inverter of this type switches the primary power through alternating halves of the inverter transformer. This switching process demands current pulses from the primary power. Radio frequency radiation may then become noticeable if the primary power impedance becomes high. Testing of this instrument was done with relatively short leads, and no appreciable RFI was experienced.

Reduction or complete elimination of this possible problem is an input line filter. However, an input line filter capable of compensating for all conditions of primary power impedance could consume as much as 200 milliwatts of power.

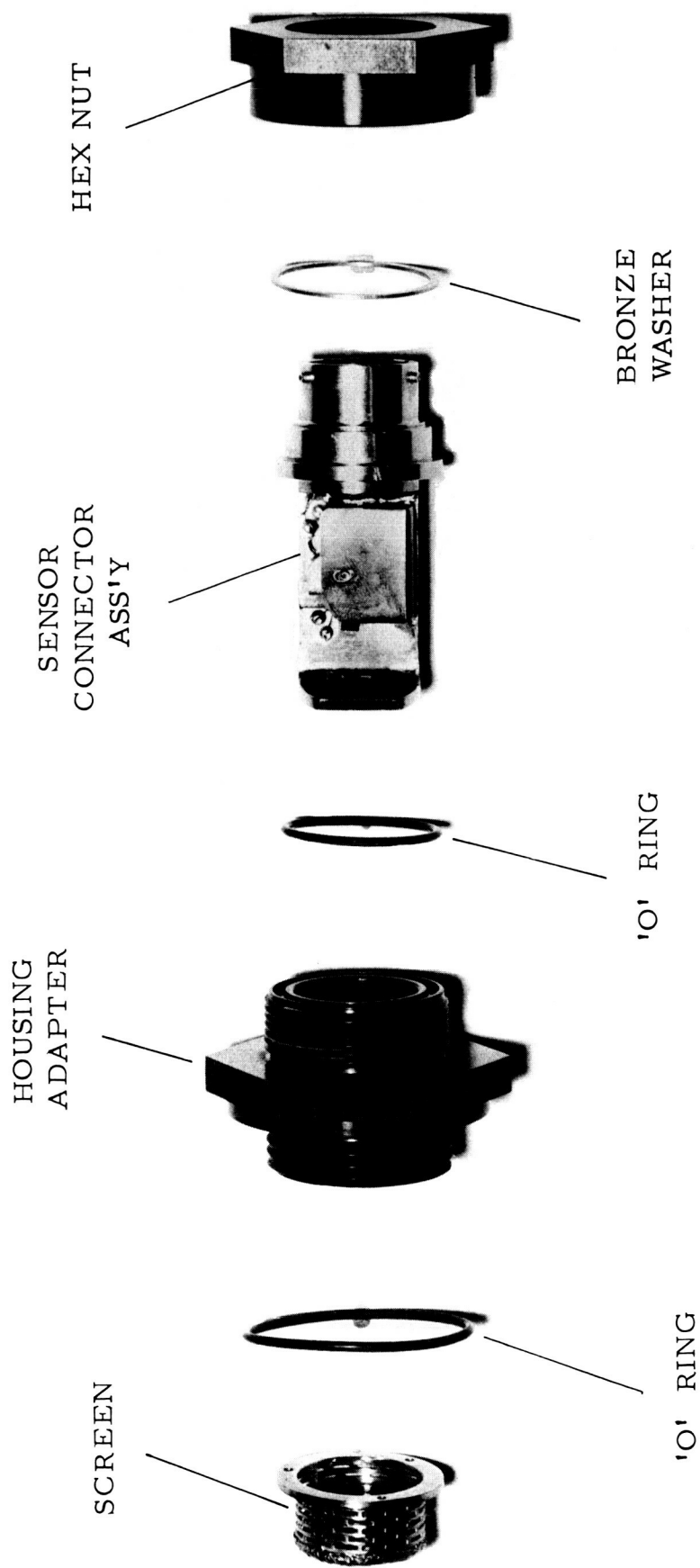


FIG. 2
SENSOR MOD. 137-S3-P EXPLODED VIEW

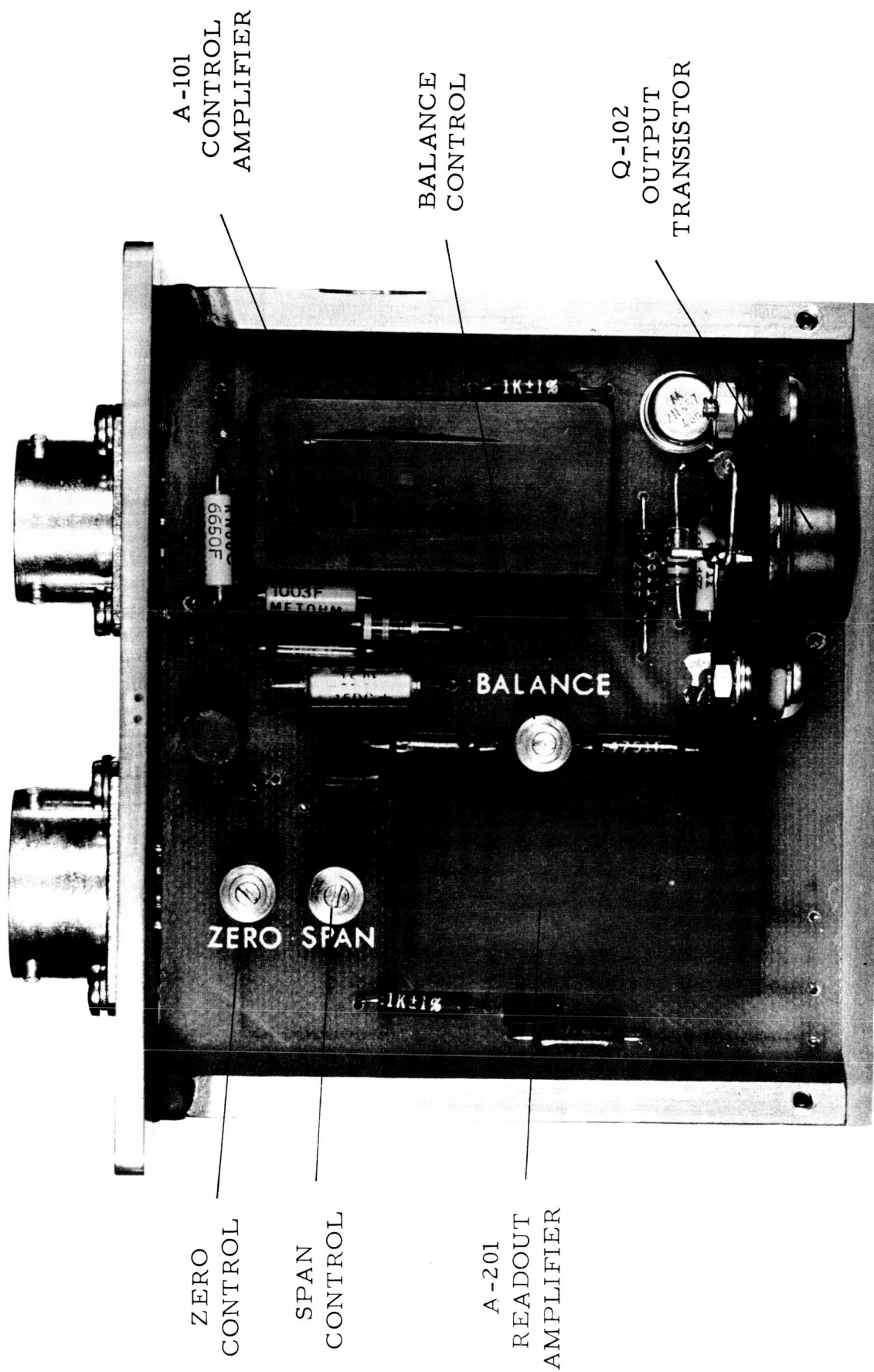


FIG. 3
READOUT AND CONTROL CIRCUITRY

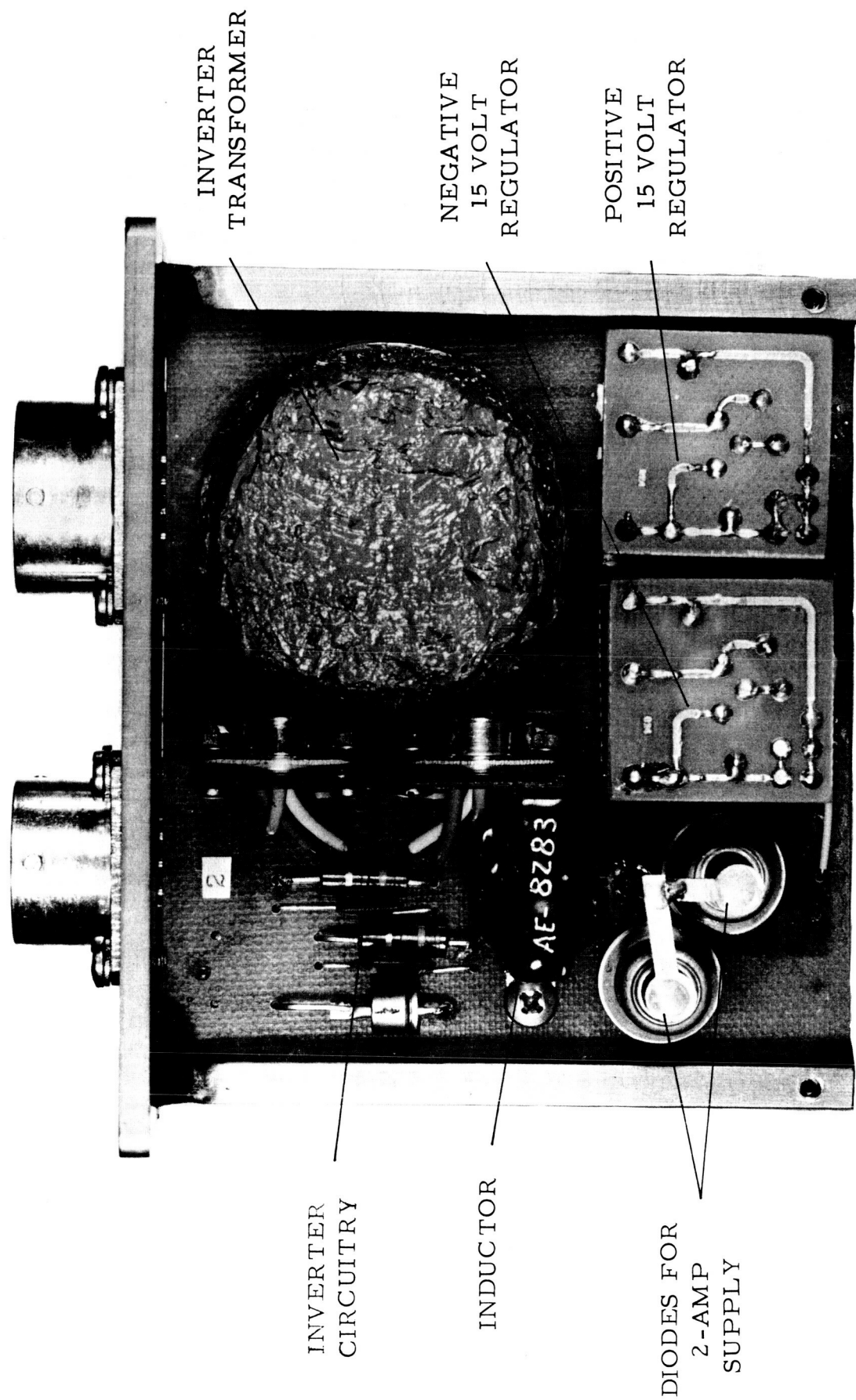
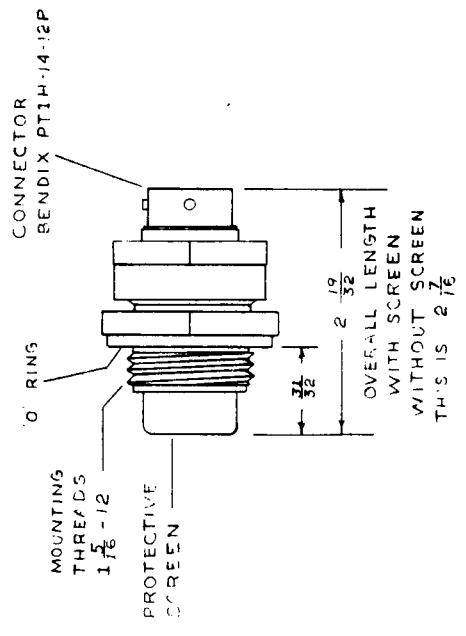
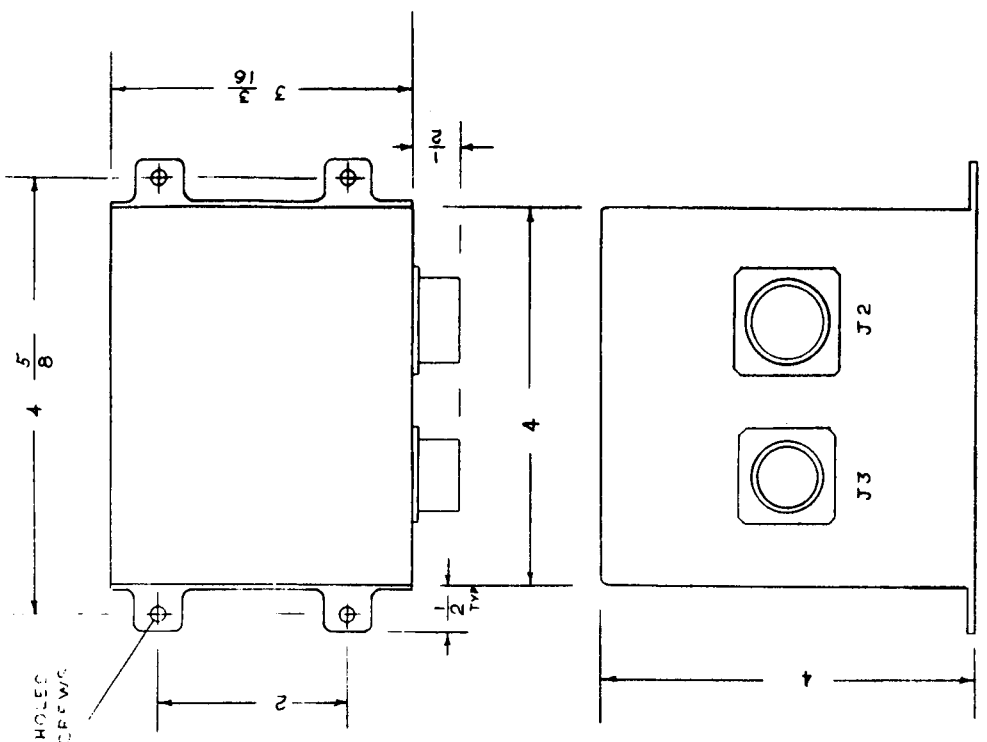


FIG. 4
INVERTER AND POWER SUPPLY

REVISIONS

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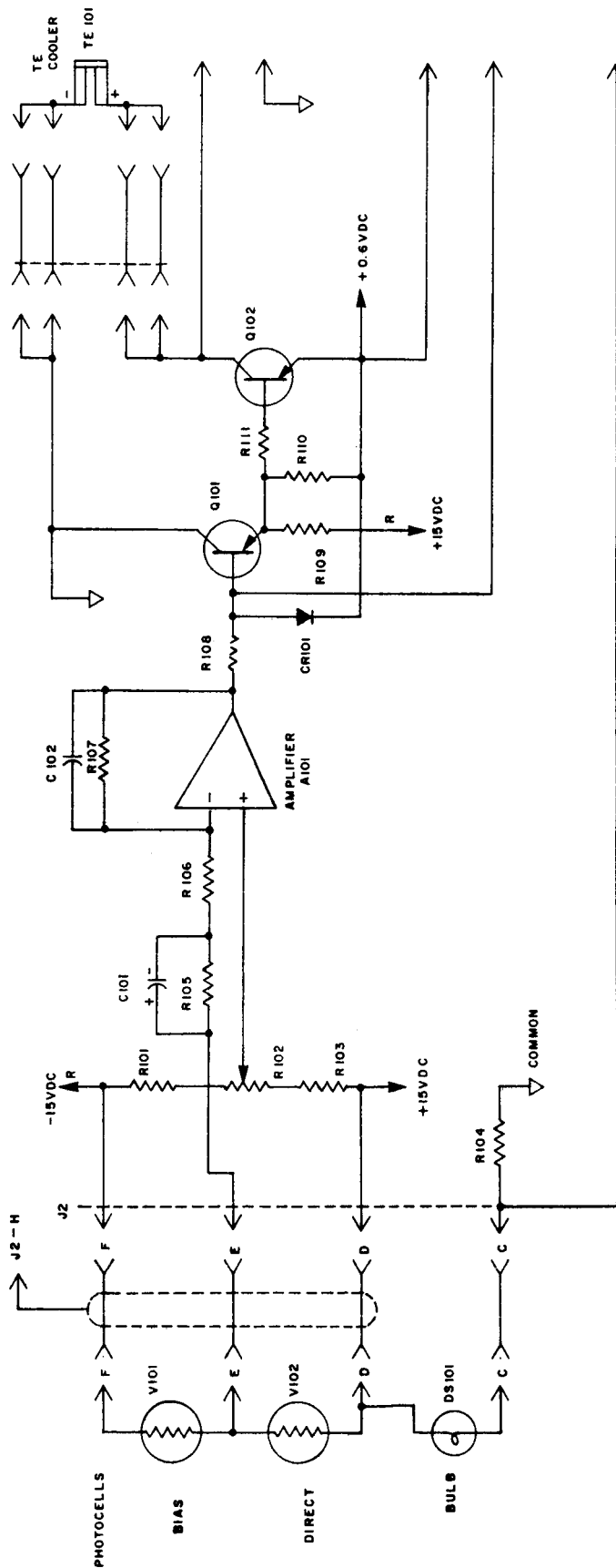


SENSOR, MODEL 137-S3-P

CONTROL UNIT, MODEL 137-C2

Cambridge Systems, Inc. model 137-C2	
MATERIAL	DR. P.C.
FINISH	DATE
DRAWING NAME	SCALE FULL
MOUNTING DIMENSIONS	APPRO
	NUMBER
	139-041

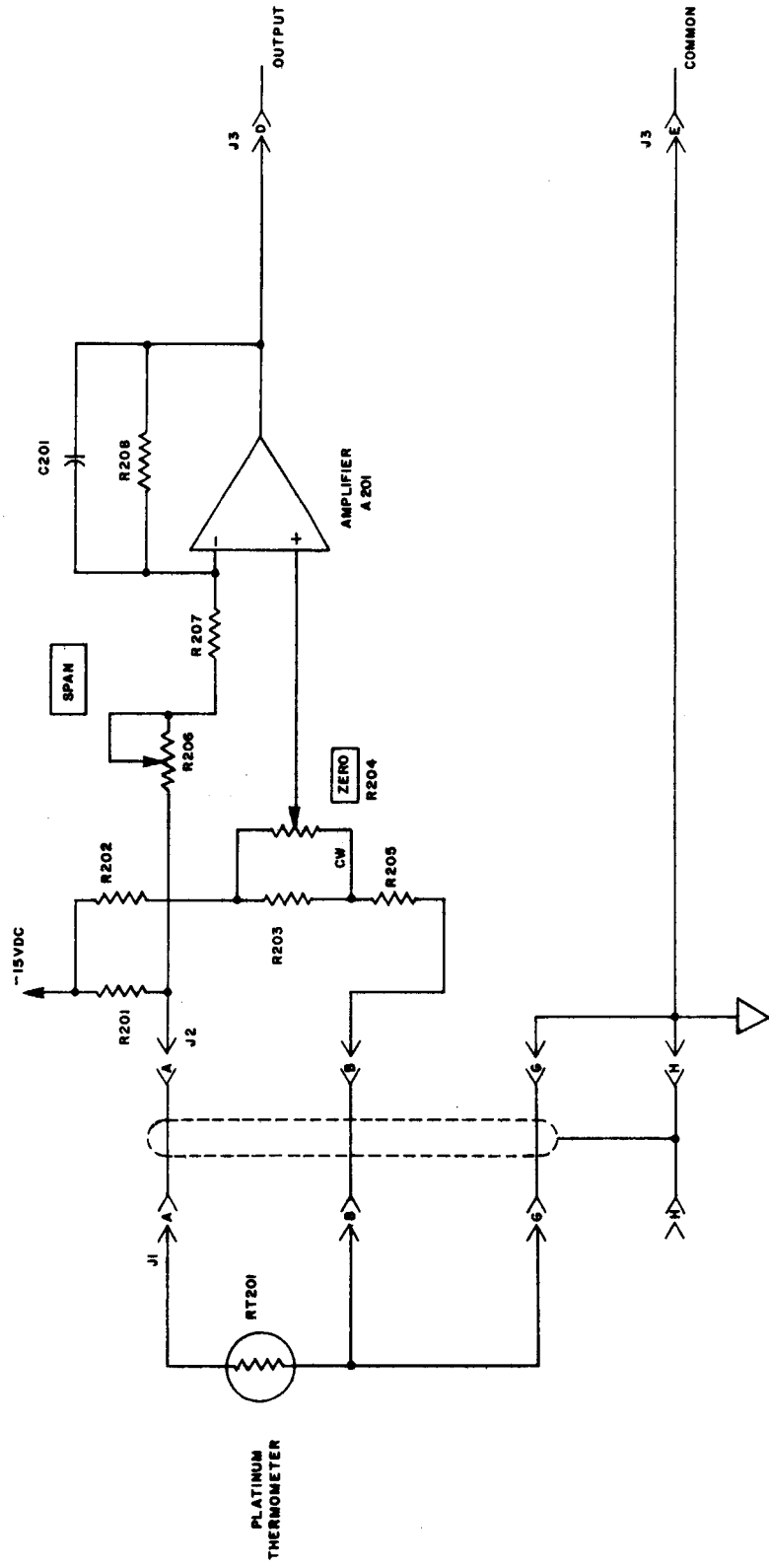
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Cambridge systems, inc.
RECORD MOUNTING

MATERIAL	DR M.S.O.L.
FINISH	DATE 9-10-64
	SCALE
	APPRO
DRAWING NAME	NUMBER
CONTROL CIRCUITRY	SKI39-004

REVISIONS		
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cambridge systems, inc.		OR M.S.O.
RENTON, MASSACHUSETTS		DATE 25-SEPT-64
		SCALE
		APPD
		NUMBER
		SKI39-005
		DRAWING NAME
		READOUT CIRCUITRY